

Solutions Network Formulation Report

Improving Public Health DSSs by Including Saharan Dust Forecasts Through Incorporation of NASA's GOCART Model Results

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1. Candidate Solution Constituents

- a. Title: Improving Public Health DSSs by Including Saharan Dust Forecasts Through Incorporation of NASA's GOCART Model Results
- b. Author: Judith Berglund, Science Systems and Applications, Inc., John C. Stennis Space Center
- c. Identified Partner: CDC (Centers for Disease Control and Prevention)
- d. Specific DST/DSS: CDC's Environmental Public Health Tracking Network
- e. Alignment with National Application: Public Health, Air Quality, and Homeland Security
- f. NASA Research Results – Table 1:

Missions	Sensors/Models	Data Product
NPOESS ¹	Input to GOCART ² : currently MODIS/MOD04 ³ ; future input could be VIIRS ⁴	Aerosol products
CALIPSO ⁵	Potential input to GOCART: CALIOP ⁶	Aerosol products
GSFC	GOCART Model	Simulated atmospheric aerosol parameters
GSFC	Input to GOCART: GEOS-4 AGCM ⁷ , an Atmospheric Forecast and Assimilation Model	Variety of parameters used in numerical weather prediction, data assimilation, and climate applications

¹NPOESS: National Polar-Orbiting Operational Environmental Satellite System; ²GOCART: Global Ozone Chemistry Aerosol Radiation and Transport; ³MODIS: Moderate Resolution Imaging Spectroradiometer; ⁴VIIRS: Visible/Infrared Imager/Radiometer Suite; ⁵CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations; ⁶CALIOP: Cloud-Aerosol Lidar with Orthogonal Polarization; ⁷GEOS-4 AGCM: Goddard Earth Observing System (version 4) Atmospheric General Circulation Model

- g. Benefit to Society: Improved ability to predict, track, and prepare for potential occurrences or outbreaks of diseases carried in Saharan dust; improved ability to provide early warning to asthmatics and those with poor respiratory health or compromised immune systems regarding Saharan dust

2. Abstract

Approximately 2-3 billion metric tons of soil dust are estimated to be transported in the Earth's atmosphere each year. Global transport of desert dust is believed to play an important role in many geochemical, climatological, and environmental processes. This dust carries minerals and nutrients, but it has also been shown to carry pollutants and viable microorganisms capable of harming human, animal, plant, and ecosystem health. Saharan dust, which impacts the eastern United States (especially Florida and the southeast) and U.S. Territories in the Caribbean primarily during the summer months, has been linked to increases in respiratory illnesses in this region and has been shown to carry other human, animal, and plant pathogens. For these reasons, this candidate solution recommends integrating Saharan dust distribution and concentration forecasts from the NASA

GOCART global dust cycle model into a public health DSS (decision support system), such as the CDC's (Centers for Disease Control and Prevention's) EPHTN (Environmental Public Health Tracking Network), for the eastern United States and Caribbean for early warning purposes regarding potential increases in respiratory illnesses or asthma attacks, potential disease outbreaks, or bioterrorism. This candidate solution pertains to the Public Health National Application but also has direct connections to Air Quality and Homeland Security. In addition, the GOCART model currently uses the NASA MODIS aerosol product as an input and uses meteorological forecasts from the NASA GEOS-DAS (Goddard Earth Observing System Data Assimilation System) GEOS-4 AGCM. In the future, VIIRS aerosol products and perhaps CALIOP aerosol products could be assimilated into the GOCART model to improve the results.

3. Detailed Description of Candidate Solution

a. Purpose/Scope

Approximately 2-3 billion metric tons of soil dust are estimated to be transported in the Earth's atmosphere each year (Griffin, 2005). Desert dust is believed to play an important role in many geochemical, climatological, and environmental processes. For example, it impacts the Earth's radiation budget; serves as a reactive surface for atmospheric gases; is involved in cloud formation and nucleation; impacts ocean carbon cycles and affects other biogeochemical processes and cycles in the oceans and on land (such as providing nutrients to rainforest plants or for marine phytoplankton growth); affects air quality and visibility; possibly suppresses tropical cyclone activity; and impacts aquatic and terrestrial ecosystem health and the health of plants, animals, and humans.

The majority of this desert dust originates from the Sahara and Sahel regions of Africa and from the deserts of Asia and the Middle East. North America is impacted by dust primarily from Africa and Asia. Asian dust impacts the western United States, Hawaii, Alaska, and western Canada in the spring (February through April) (Griffin, 2005). African dust is carried by trade winds in the summer (June through October) to the Caribbean and to the eastern United States—as far west as New Mexico and as far north as Maine (Perry et al., 1997; Griffin, 2005).

African and Asian dust air masses transport minerals and nutrients (iron, phosphorous, etc.), but they also carry persistent organic pollutants (pesticides, herbicides, dioxins, etc.), industrial emissions, trace metals, radioactive isotopes, and viable microorganisms (wide variety of bacteria, as well as fungi and viruses) (Kellogg and Griffin, 2003; Holmes and Miller, 2004; Shinn et al., 2003).

In 2000, the USGS (U.S. Geological Survey) in St. Petersburg, FL, began the USGS Global Dust Program (initially funded by NASA) to investigate the microorganisms in dust masses (initially in Saharan dust) and the potential effects of the microorganisms on plant, animal, and human health (Shinn et al., 2003). Griffin et al. (2001) at USGS and other collaborating university researchers were able to isolate and identify (using DNA sequencing of the ribosomal gene) over 200 viable bacteria and fungi in samples from St. John in the U.S. Virgin Islands in 2000 during dust transport events, of which ~25–30 percent are species known to cause disease in a broad range of plant and animal life and ~10 percent are known opportunistic human pathogens that can affect compromised immune systems (Griffin and Kellogg, 2004; Griffin, 2005).

The U.S. National Institutes of Health's National Institute of Allergy and Infectious Diseases has identified airborne dust as the primary source of allergic stress worldwide. African dust air masses are being linked to increased rates of asthma, allergies, and other respiratory problems in the Caribbean and in the southeastern United States because of the contents (viable microorganisms) and the particle size and mineral coating on the dust. Levels of asthma on Barbados and Trinidad are among the highest in the world and have increased 17-fold since 1973 (Shinn et al., 2003), which roughly parallels the increased Saharan dust concentrations measured on Barbados since the late 1960s

(Prospero, 1999, 2001). Gyan et al. (2005) found a positive correlation between African dust events and pediatric hospital admissions for acute asthma in Trinidad.

Many of the viable microorganisms identified in Saharan dust by Griffin et al. (2001) and others are known to cause respiratory diseases (allergic reactions, asthma, pulmonary infections), cardiovascular diseases, or skin infections. Other microbes in airborne dust known to be pathogenic to people include those causing plague, anthrax, tuberculosis, and influenza (Weinhold, 2004). Samples of airborne fungi from Saharan dust in Dominica in 2002 found 4 species known to cause respiratory distress and found 1 species that causes an aggressive pulmonary allergic response (De la Mota et al., 2003).

In addition to the content of the dust, the size of the dust causes respiratory health problems. Studies on Barbados and Miami show that one-third to one-half of the Saharan dust mass that arrives in these areas is less than 2–2.5 μm ($\text{PM}_{2.5}$) in aerodynamic diameter (Prospero, 1999, 2001). Fine particles ($<2.5 \mu\text{m}$) are believed to have the greatest impact on human health because they can efficiently penetrate into the lungs (Prospero, 1999). Saharan dust may also cause health problems because of its iron coating (3–5 percent iron). Research suggests that aerosols coated with first-row transition metals, including iron, are particularly efficient in producing an inflammatory response in the lungs (Prospero, 1999, 2001; Taylor, 2002).

Saharan dust has also been shown to carry plant and animal pathogens. Plant pathogens include the fungus that causes sugarcane rust (Purdy et al., 1985) and coffee rust, or pathogens known to affect crops such as cotton, peaches, rice, and beans (Griffin et al., 2001; Taylor, 2002; Kellogg and Griffin, 2003). Animal disease outbreaks have also been linked to dust events. Outbreaks of foot-and-mouth disease in livestock were reported in Korea and in Europe a few days after the arrival of dust from Asian and African dust storms (respectively) on multiple occasions (Ralloff, 2001). Smith et al. (1996) and Shinn et al. (2000) have linked coral and Caribbean sea-fan diseases with African dust transport.

Given the impact of global desert dust transport on human, animal, plant, and ecosystem health, Saharan dust distribution and concentration forecasts could be incorporated into existing DSSs to aid in Public Health, Air Quality, and Homeland Security National Applications. Because Saharan dust has been shown to carry viable microorganisms that are harmful to human, animal, and plant health, and because it has been linked with increases in respiratory illnesses, this candidate solution recommends incorporating Saharan dust distribution forecasts from the NASA GOCART global dust cycle model into a public health DSS, such as the CDC's EPHTN, for the eastern United States (especially the southeast and Florida) and U.S. Territories in the Caribbean to aid in early warning for potential disease outbreaks or increases in respiratory illnesses such as asthma attacks.

b. Identified Partner(s)

The partner identified for this candidate solution would be the CDC and the use of its national EPHTN DSS. The CDC's mission is to promote health and quality of life by preventing and controlling disease, injury, and disability. The CDC strives to protect people's health and safety, to provide reliable health information, and to improve health through strong partnerships (CDC, 2006). One of the CDC's overall health protection goals is to protect communities from infectious, occupational, environmental, and terrorist threats. In alignment with its mission and goals, and in response to a January 2001 Pew Environmental Health Commission report that described the lack of a national system of health tracking, the CDC developed a plan (and received congressional funding in 2002) for a national Environmental Public Health Tracking Network, or EPHTN (CDC et al., 2006a). The EPHTN is one of the CDC's PHIN (Public Health Information Network) components. The CDC has established a formal agreement with NASA, with the EPA (U.S. Environmental Protection Agency), and with other federal agencies (CDC et al., 2006a) to conduct research relevant to tracking public health threats and to assist with developing methodologies that can be used in tracking.

When fully operational in 2009, the CDC's EPHTN will be a Web-based, secure, nationwide network that will integrate, standardize, and provide timely access to electronic data from environmental monitoring systems (including environmental hazards data) and public health information systems (including human exposure and health effects surveillance systems) collected by a wide variety of local, state, and federal agencies that can be used to plan, apply, and evaluate actions to prevent and control environmentally related diseases (CDC et al., 2004). The EPHTN will also promote interoperable systems via compliance with PHIN standards and will be able to exchange data with the EPA Exchange Network, where applicable; to support data exchange between partners; to provide a toolset for data analysis (spatially and temporally), visualization, reporting, and monitoring; and to provide the necessary security and protection to sensitive or critical data and systems. The Network will be a national early warning system for the rapid identification of health threats (including toxic chemical releases). Stakeholders and users include federal, state, local, and tribal public health and environmental agencies and staff, universities, healthcare providers, laboratories, legislators, advocacy groups, industry and trade groups, and the general public (CDC et al., 2004). The CDC has funded multiple projects in the United States to begin to implement the EPHTN (CDC et al., 2006b).

c. NASA Earth-science Research Results

The focus of this candidate solution is the use of the output from the NASA GOCART model in the EPHTN. Aerosol products from NASA's MODIS—specifically the MOD04 products—are currently used as input to the GOCART model. MODIS aerosol products (including AOT (aerosol optical thickness), particle size distribution, and aerosol type) are produced once daily at a horizontal spatial resolution of 10 km (10x10 1-km (at nadir) pixel array) (NASA, 2007).

Future inputs to the GOCART model might include aerosol products from VIIRS. In addition, GOCART model developer Chin et al. (2005) suggested that assimilation of aerosol vertical distribution/profile products from CALIOP into the GOCART model are likely to significantly enhance the PM_{2.5} estimation from the model.

VIIRS on NPOESS and NPP (NPOESS Preparatory Project) will be used to produce aerosol products—AOT, aerosol particle size parameter, and identification of suspended matter—with global coverage on a daily basis (except over bright surfaces and under cloudy conditions) using separate retrieval algorithms over land and ocean (Vermote et al., 2002). VIIRS has 22 spectral bands covering 412 nm to 12 µm, including 16 radiometric bands (742 m horizontal resolution at nadir), 5 imaging bands (371 m horizontal resolution at nadir), and a day-night band (Shettle et al., 2007).

CALIOP on the CALIPSO satellite was launched April 28, 2006. CALIOP uses two diode-pumped Nd:YAG lasers and has a receiving system with three channels at 1064 nm and 532 nm (with parallel and perpendicular polarizations). The instrument has a 70–90 m footprint and a sampling resolution of 30–60 m in the vertical and 333 m in the horizontal. CALIOP is in a highly inclined, sun-synchronous 705 km circular orbit, allowing for measurements of clouds and aerosols over a wide range of latitudes with a 16-day repeat cycle. Aerosol-related CALIOP Level 1 data includes profiles of 532 nm/1064 nm total attenuated backscatter and 532 nm perpendicular attenuated backscatter (Winker et al., 2006; Hamill and Redemann, 2006). Winker (2006) showed that Saharan dust can be observed and distinguished from biomass-burning dust and clouds in Level 1 data. The aerosol-related CALIOP Level 2 data products include aerosol layer heights, thickness, optical depth, and type at 5 km; an aerosol profile product (aerosol extinction and attenuation-corrected backscatter at 40 km); and a vertical mask (cloud/aerosol identification and type) (Winker et al., 2006).

d. NASA Earth-Science Models

The GOCART model assesses dust sources, estimates annual emissions, and simulates the paths of major tropospheric aerosol components, including sulfate, dust, black carbon, organic carbon, and sea-salt aerosols. It can also trace and simulate the paths of radon, lead, and carbon monoxide. The

GOCART model was developed by Dr. Mian Chin, who was previously at the Georgia Institute of Technology and is now in the Atmospheric Chemistry and Dynamic Branch, Laboratory for Atmospheres, GSFC/NASA (Chin, 2004a,b; NASA, 2004a).

Chin et al. (2000) initially developed the model to simulate the distribution of sulfur species in the atmosphere. The model solves the continuity equation, which includes the emission, chemistry, advection, convection, diffusion, and dry and wet deposition of each aerosol species. Ginoux et al. (2001, 2004) incorporated the emission, transport, and removal processes of dust sizes ranging from 0.1 to 6 μm radius into the GOCART model. The GOCART model currently processes the paths of particle sizes ranging from 0.1 to 10 μm in radius. However, particles larger than 6 μm generally have short atmospheric lifetimes (i.e., less than a few hours) because of gravitational settling (Tegen and Fung, 1994), thus limiting their significance in global scale studies, whereas smaller particles can stay aloft for weeks and can travel greater distances.

Inputs to the GOCART model currently include the MODIS/MOD04 aerosol product and assimilated meteorological fields from the NASA GEOS-DAS GEOS-4 AGCM. The datasets from GEOS-4 AGCM are generated by the Goddard GMAO (Global Modeling and Assimilation Office). Inputs to GEOS-4 AGCM are atmospheric pressure, humidity, and wind velocity from the GISS Model III (Goddard Institute for Space Studies Model III). The output dataset from GEOS-DAS GEOS-4 AGCM consists of 25 meteorological fields that represent a combination of results from the general circulation model and the actual observed meteorological readings of winds, temperature, pressure, water vapor, and other weather factors (NASA, 2004b). The model product and validation information can be accessed from the GMAO Web site (<http://gmao.gsfc.nasa.gov/>). GEOS-4 AGCM has the following resolutions: temporal (30 min); vertical (55 levels); horizontal (50–200 km). The range of the GEOS-4 AGCM model is as follows: temporal (days to decadal); vertical (surface to 60 km); horizontal (global) (NASA, 2004b).

The GOCART model has the same horizontal resolution as GEOS-DAS: 2° latitude by 2.5° longitude, or 1° latitude x 1.25° longitude (to better match the resolution of MODIS aerosol products for intercomparison, with plans for increased resolution). GOCART has a vertical resolution of 20 to 55 vertical layers (depending on the version of GEOS-DAS). The temporal resolution of the model is 15 minutes (interpolated) to 6-hour time steps. The model range is as follows: temporal (1980 to present (+5 day projection for 5-day dust forecasts)); vertical (sea level to 0.001 mbar); horizontal (global scale) (NASA, 2004a; Chin, 2004a,b).

GOCART model outputs include dust emission, sea-salt emission, wavelength-dependent optical thickness of individual (for a given aerosol type and mass) and total aerosols, column burden of individual aerosol species, individual and total aerosol concentrations, 3-D distribution of each aerosol type, aerosol particle size, absorption, single scattering albedo, heating/cooling rates, and aerosol radiative forcing (NASA, 2004a; Chin, 2004a,b). The original data format for GOCART is ASCII with a resolution of 2x2.5 degrees (Chin, 2004c). GOCART model products are available from the model Web site or by contacting the POC, Dr. Mian Chin (Chin, 2004a,b; NASA, 2004a).

e. Proposed Configuration's Measurements and Models

Research has shown that large amounts of Saharan dust are transported to the eastern United States and Caribbean in summer months. These dust air masses carry minerals, chemicals, pollutants, and viable microorganisms capable of harming human, animal, plant, and ecosystem health. Saharan dust has been linked to increases in asthma and respiratory illnesses because of its viable microbial content, its size, and its iron coating. By combining environmental monitoring data with health surveillance systems, the CDC's EPHTN allows public health officials and healthcare providers to analyze the impact of environmental events on public health for early detection and rapid identification of health threats. Currently, the EPHTN does not incorporate Saharan dust forecasts. By incorporating dust forecasts (dust distribution, concentration, particle characteristics) from the

GOCART model into EPHTN, users of EPHTN (clinicians, public health officials, physicians, etc.) can better provide early warning to asthmatics and to those with compromised immune systems regarding potential respiratory ailments. Users can also better prepare for potential disease outbreaks in humans, animals, or plants associated with the arrival of Saharan dust. CALIOP and simulated VIIRS aerosol products could also be assimilated into the GOCART model to determine improvements in the modeled outputs, such as modeled $PM_{2.5}$, when compared to results using the current GOCART model input of MODIS aerosol products. While the scope of this candidate solution was limited to the incorporation of Saharan dust forecasts, the candidate solution could also be applied to the incorporation of Asian dust forecasts for the western United States.

4. Programmatic and Societal Benefits

This candidate solution aligns with the following National Application elements: Public Health, Homeland Security, and Air Quality. By incorporating environmental data such as forecasts of Saharan dust distributions and concentrations from NASA's GOCART model into the CDC's EPHTN Web-based surveillance system for the eastern United States and Caribbean, healthcare professionals and public health officials can better detect and prepare for potential outbreaks of infectious disease caused by viable microorganisms carried in the dust and can alert asthma sufferers and those with compromised immune systems or poor pulmonary health to the potential hazard. It would also help healthcare professionals to better understand the environmental conditions that could exacerbate certain symptoms and the links between the environment and medical conditions and disease. Viable microorganisms transported in the dust can impact humans, but they can also impact animals and plants, including economically important crops. Animal diseases can also impact humans, and thus it is important to identify and control infectious diseases in animals too. Because anthrax and other human, animal, and plant pathogens, as well as harmful chemicals, can survive global transport in dust, this candidate solution may also help to identify potential bioterrorist attacks that endanger our homeland security. Also, this candidate solution aligns with the Air Quality National Application because Saharan dust concentrations greatly impact air quality. In Miami in the summer, Saharan dust concentrations often exceed those from anthropogenic sources (Prospero, 1999) and are being taken into account when determining the city's compliance with EPA $PM_{2.5}$ standards (Federal Clean Air Act limits) (Prospero, 1999; Raloff, 2001).

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